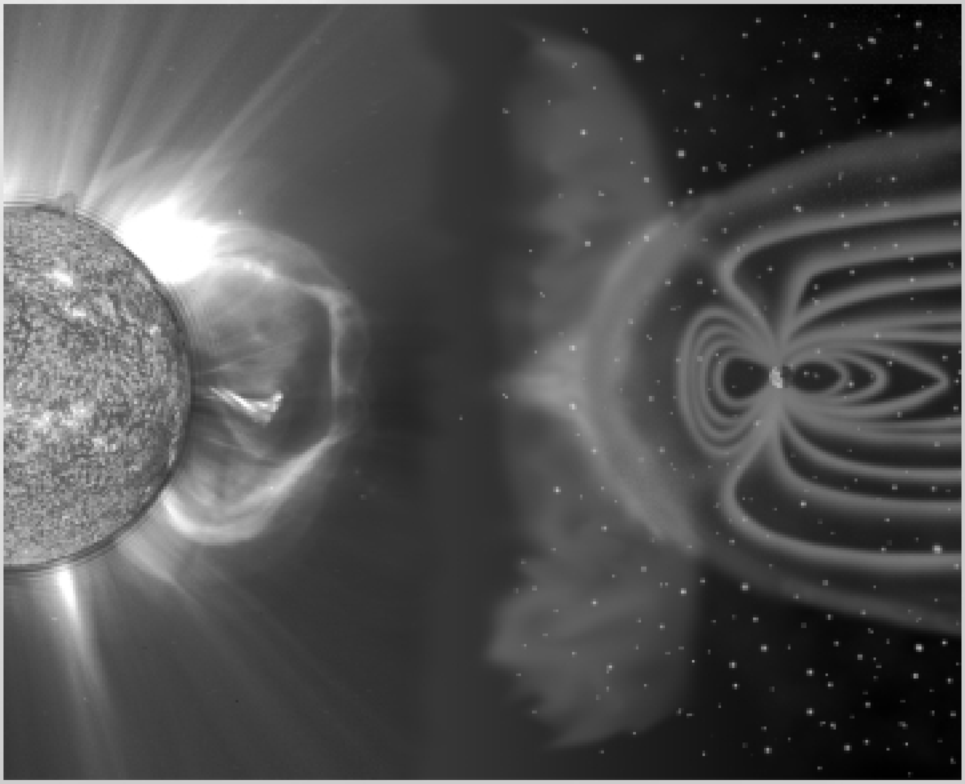
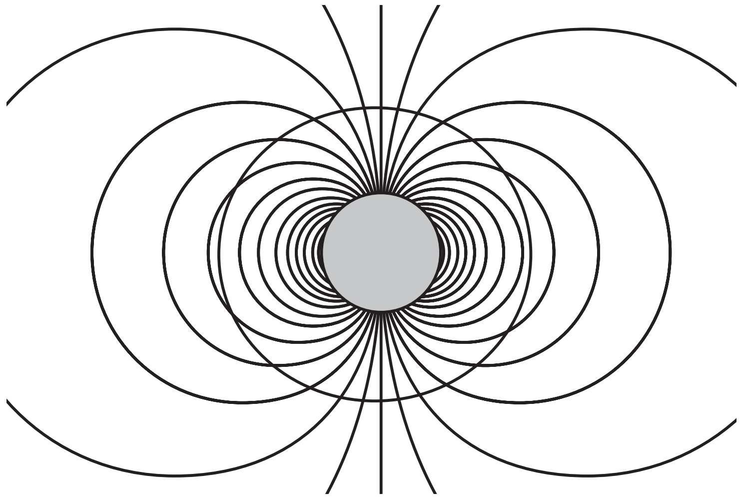


MAGNETISM

BACKGROUND:

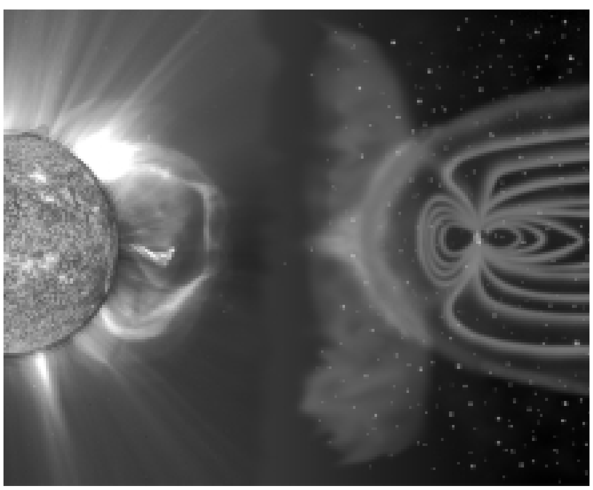
A spherical magnet in an otherwise empty region of space would have a magnetic field approximately modeled in the figure on the next page.

The Earth's magnetic field close to the Earth can be thought of approximately as a spherical magnet. Notice that at the poles the field is nearly vertical and at the equator it is nearly horizontal. More than 90% of the Earth's magnetic field measured is generated internal to the planet in the Earth's outer core. This portion of the geomagnetic field is often referred to as the Main Field. The Main Field creates a cavity in interplanetary space called the magnetosphere, where the Earth's magnetic field dominates in the magnetic field of the solar wind. The magnetosphere is shaped somewhat like a comet in response to the dynamic pressure of the solar wind. It is compressed on the side toward the Sun to about 10 Earth radii (R_E is 6400 km) and is extended tail-like on the side away from the Sun to more than 100 Earth radii.



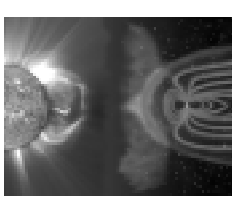
The inner circle represents the outer core of the Earth. The outer circle represents the surface of the Earth

The shape of the Earth's magnetic field is formed by the interaction of several important features. One feature is, of course, the Earth's internal magnetism. Another feature is the interplanetary magnetic field. This magnetic field arises at the Sun and extends into interplanetary space. The interplanetary magnetic field is formed by currents of plasma within the Sun and within the solar wind. This magnetic field pattern spirals outward from the Sun to fill space throughout the solar system. The third significant feature contributing to the shape and activity of the Earth's magnetic field is the solar wind, the plasma streaming constantly from the Sun in all directions.



Humans have been aware of and made use of the magnetic field of the Earth for the past 2 millennia. Mariners, following the example of the Chinese, used the magnetic properties of magnetite and magnetized metals to find their way relative to the fixed orientation of the compass needle in the Earth's magnetic field. Today, we use magnets in a variety of ways, from floating fast spinning CDs in our computers, stereos and TVs, to magnetic resonance imaging, to sticking paper to our refrigerators. Magnetism is a noncontact force. The magnet can affect materials across an intervening space. That is, we do not have to be at the location of the source object to detect it. We say that a magnet creates a magnetic field or a region of influence in the space around the magnet.

In the following activities, students will investigate the shape of the magnetic field of a bar magnet and extend their understanding of magnetism to a more complex magnetic system—the Sun-Earth system. The bar magnet is the prime example of a dipole magnet. Data will be collected in Activity 1 by placing a student-made magnetometer at various locations relative to a bar magnet and recording the direction of alignment of the magnetometer. Students will learn about magnetic field direction by examining the data. During the Activity 2, students will be prompted to consider whether the magnetic field of the Earth is represented in their data, and be further prompted to remove the effect. Of course, the magnetic field of the Earth is always present, but it is overwhelmed by the dipole



field close to the source magnet. Due to the field strength of the bar magnet decreasing as the cube of the distance to the magnet, the influence of the Earth's field will easily be seen within 50 centimeters of the bar magnet. Activity 3 asks students to use the magnetometer to map the combined field of two aligned dipoles and two anti-aligned dipoles. This sets the stage nicely for an investigation into the interacting magnetic fields of the Sun and of the Earth in Activity 4.

NATIONAL SCIENCE STANDARDS:

National Science Standards (NSES)

Content Standards (Grades 9-12)

- Scientists conduct investigations for a wide variety of reasons. For example, they may wish to discover new aspects of the natural world, explain recently observed phenomena, or test the conclusions of prior investigations or the predictions of current theories.

  This is done if the student is considered to be a scientist discovering a new aspect of the world (magnetism) in order to understand aurora and other Sun-Earth interactions.

- Scientists rely on technology to enhance the gathering and manipulation of data. New techniques and tools provide new evidence to guide inquiry and new methods to gather data, thereby contributing to the advance of science. The accuracy and precision of the data, and therefore the quality of the exploration, depends on the technology used.

  Addressed through the building of the magnetometer and analysis of maps generated from magnetometer.

- Scientific explanations must adhere to criteria such as a proposed explanation must be logically consistent; it must abide by the rules of evidence; it must be open to questions and possible modification; and it must be based on historical and current scientific knowledge.

  The discussion questions are designed to create the above environment of explanation.

Benchmarks for Science Literacy

Project 2061 (Grades 9-12)

- Magnetic forces are very closely related to electric forces and can be thought of as different aspects of a single electromagnetic force. Moving electric charges produce magnetic forces and moving magnets produce electric forces. The interplay of electric and magnetic forces is the basis for electric motors, generators, and many other modern technologies, including the production of electromagnetic waves.

  As we relate the solar wind (stream of charged particles) to interaction with magnetosphere, we address this.

- Scientists assume that the universe is a vast single system in which the basic rules are the same everywhere. The rules may range from very simple to extremely complex, but scientists operate on the belief that the rules can be discovered by careful, systematic study.

- We are studying experiments in a lab to understand Sun-Earth interactions. What we do in the lab must explicitly replicate and inform about these interactions.

  Use tables, charts, and graphs in making arguments and claims in oral and written presentations.

  Explicitly built in to creation of maps and interpretation of maps.

Grade 8:

- Electric currents and magnets can exert a force on each other.

  Explicitly built into lessons.

- When similar investigations give different results, the scientific challenge is to judge whether the differences are trivial or significant, and it often takes further studies to decide. Even with similar results, scientists may wait until an investigation has been repeated many times before accepting the results as correct.

  As students predict multidipole fields, differences in maps will need to be accounted for.

National Educational Technology Standards (NETS)

Grades 9-12

- Technology research tools.
- Students use technology to locate, evaluate, and collect information from a variety of sources.

  Use of Internet as information collection tool explicitly built in.
- Technology problem-solving and decision-making tools.
- Students use technology resources for solving problems and making informed decisions.

  Explicitly addressed in activity about solar wind and magnetosphere interaction.

Mathematics Standards (NCTM)

Grades 6-8

- Formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them.
- Formulate questions, design studies, and collect data about a characteristic shared by two populations or different characteristics within one population.
- Select, create, and use appropriate graphical representations of data, including histograms, box plots, and scatterplots.
- Develop and evaluate inferences and predictions that are based on data.
- Use observations about differences between two or more samples to make conjectures about the populations from which the samples were taken.
- Use conjectures to formulate new questions and plan new studies to answer them.

  Mapping of multiple dipole fields addresses these standards.

Measurement Standard for Grades 9-12

Understand measurable attributes of objects and the units, systems, and processes of measurement.

Apply appropriate techniques, tools, and formulas to determine measurements.

- Analyze precision, accuracy, and approximate error in measurement situations.

Discussion leads students through understanding what magnetometer measures. Measuring ambient field and finding local variations due to other sources and applying this knowledge to reinterpretation of dipole maps address this standard.

Communication Standard for Grades 9-12

- Organize and consolidate their mathematical thinking through communication.
- Communicate their mathematical thinking coherently and clearly to peers, teachers, and others.
- Analyze and evaluate the mathematical thinking and strategies of others.

Connections Standard for Grades 9-12

- Recognize and apply mathematics in contexts outside of mathematics.

Representation Standard for Grades 9-12

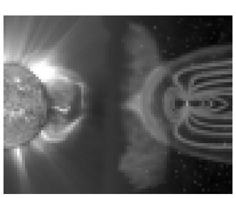
- Use representations to model and interpret physical, social, and mathematical phenomena.

INSTRUCTIONAL OBJECTIVES FOR ACTIVITIES 1 AND 2

Students will use the magnetometer to map the field of a bar magnet. The map will indicate direction of field only, and will resemble a dipole field. Students will use the magnetometer to map the ambient field due to the Earth. Students will analyze the maps produced for patterns and trends. Students will identify and examine methods for removal of the Earth's magnetic influence on the measurements used to make the map.

VOCABULARY:

- **Magnetic force:** The fundamental force exerted by a source magnet which will cause the motion of



a test magnet to change or to cause its orientation relative to a fixed direction to change.

- **Orientation:** The direction that defines the position of one object in relation to another. Within this activity, we take the definition of direction as the line joining the poles of a magnet relative to a fixed line (often determined by another set of magnetic poles.)
- **Magnetic Field:** An abstract representation of the effect of a magnet on the space in which it is found. The field is often represented by lines that show how a test magnet would align itself within a source field. This is different from the electrostatic field that represents the direction along which a positive particle would feel a force. For magnetism, the field line represents the direction along which a magnet feels a torque of Zero Nm.
- **Dipole:** A situation where two conjugate sources of field are in proximity and together influence the space around them. Magnetism is found in dipole constructions at its simplest occurrence. That is, one cannot separate the conjugate poles, often termed the North and South poles, of a magnet. In electrostatics, a positive charge is one monopole, a negative charge is the conjugate monopole, and each can be found independently of the other. In gravitation, a mass is a self-conjugate pole.
- **Super-position Principle:** The principle tells us that when two similar phenomena occur at the same time and place, we will see the sum of the two phenomena, rather than the original 2 separately. Vector addition is exploited to represent this principle.

ACTIVITIES:

Preparing for the Activity

Student Materials:

Materials for one magnetometer—4 students per group

- 2-liter soda bottle or tennis ball canister
- 2 ft. of sewing thread
- 1 small bar magnet
- 1—3 x 5 index card
- 1 mirrored dress sequin
- 1 adjustable high-intensity lamp
- scissors
- 1 meter stick
- super glue
- 1—1 inch piece of soda straw

Mirror sequins may be obtained from any craft store.

Bar magnets may be obtained from this Web site: *http://www.wondermagnet.com/dev/magnets.html* Item #27, $2.01 each.

Students could bring in 2-liter soda bottles.

A desk lamp could be substituted for the high-intensity lamp.

Additional materials for Activities 1-4

- Cow magnet (source: *www.mastermagnetics.com*, part # DMCP5). A strong bar magnet may be substituted.
- 3-4 sheets of poster paper, at least 2 ft on edge, per group.
- Tape
- Wall space for hanging and displaying student generated maps.

Time

5-6 class periods (45-50 minutes)

4 homework periods

Advance Preparation

- Students will need large, flat, clean and dry areas to work on. The floor is acceptable if sufficient table surface is not available.

- Scout the room for extraneous sources of magnetic fields. Computers, electrical lines, any operating electrical equipment, refrigerators, and of course magnets, are all items that will lead to systemic errors. While some can be minimized or removed, some cannot. Anticipate this when guiding the discussion following data collection.
- Practice before class using a magnetometer and making a dipole map for the recorded observations. Even a few minutes will give you significant insight for assisting students.

Activity 1
Mapping the Field of a Dipole Magnet

Teacher Instructions

1. Assignment for the evening before Activity 1

Please discover when magnetism was first noticed and exploited by human kind. What was done with the discovery? How was it explained? Was it put to general use or was it seen as a curiosity?

Suggested Web sites:

- Dr. David Stern (NASA) has an online book on magnetism at *http://www-spof.gsfc.nasa.gov/Education/Imagnet.html*
- From the official Web server of the State of Hawaii Schools *http://gamma.mhpcc.edu/schools/hoala/magnets/history.htm*
- A Timeline of Magnetism (and Optics) Phenomena *http://history.hyperjeff.net/electromagnetism.html*
- From the University of Washington, a Web site built by a graduate student *http://www.ocean.washington.edu/people/grads/mpruis/magnetics/*

2. Setting the Stage—opening discussion. Ask the question, "Where does a magnetic force begin and end in space around a magnet? What evidence reveals that a magnetic force is present." Try to elicit these responses from students' previous experience with magnets.
   - Magnets affect other magnets and metals.
   - Magnetic influence or strength is not related to size of magnet.
   - Magnetic influences extend through space, but get weaker with distance.
   - Magnets have well differentiated ends or poles. There are two poles.
   - Like poles repel; unlike poles attract.

3. Handout materials and instructions for construction of magnetometer—see page 47.

When students have completed the magnetometer, hand out materials and instructions for remainder of activity. Give students 20-30 minutes to complete a map. Circulate, answering questions. Questions can be asked motivating students to think critically about the data and the data collection procedure. Some suggestions follow.

- Where on the line segment is the measured magnetic field direction best represented?
- Is the measured magnetic field parallel to the entire drawn directed line segment or just some part of the drawn arrow?
- What technique did you use to insure you made your arrow directly below the pivot or center point of the sensor magnet?
- Can you state the resolution (the smallest difference in position that also shows a difference in magnetic field direction) of your procedure?

One of the potentially challenging tasks is to draw a set of smooth curves on the maps representing the overall pattern revealed. Certain measurements may not fit the general curve. These individual measurements may have to be ignored, but a solid reason for doing so is required. It is pedagogically useful to prompt students to repeat measurements or to ask several other groups to make some measurements at the same location (but obscure the original troubling one to avoid bias!). This again gets back to the scientific method and it also raises the qualities of collegiality and cooperative effort, both celebrated qualities of work in groups and science labs.

The smooth curves should be approximately tangent to the arrow drawn at a location. This can be hard, and will be affected by such things as "lack of artistic talent," learning disabilities affecting hand-eye coordination and spatial awareness/representation. The goal is NOT a map that emulates the textbook